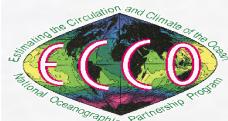


Formation of the Arctic Upper Halocline in a Coupled Ocean and Sea-ice Model

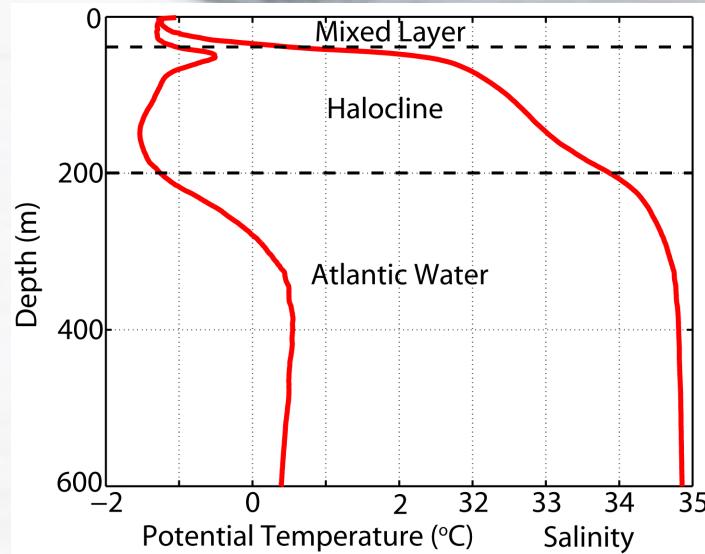
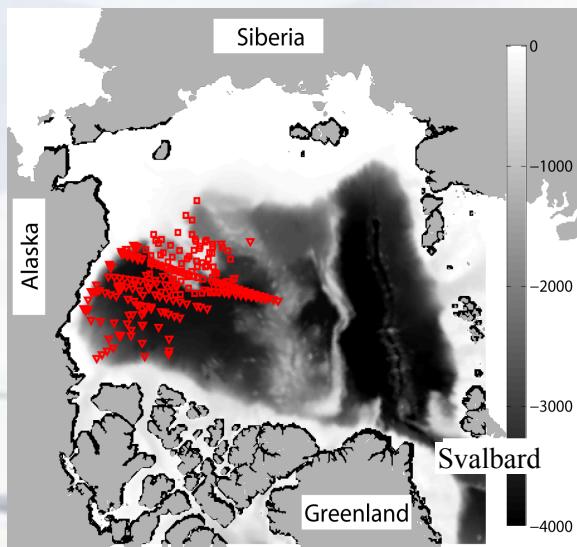
Nguyen, An T., D. Menemenlis, R. Kwok,
Jet Propulsion Laboratory, California Institute of Technology



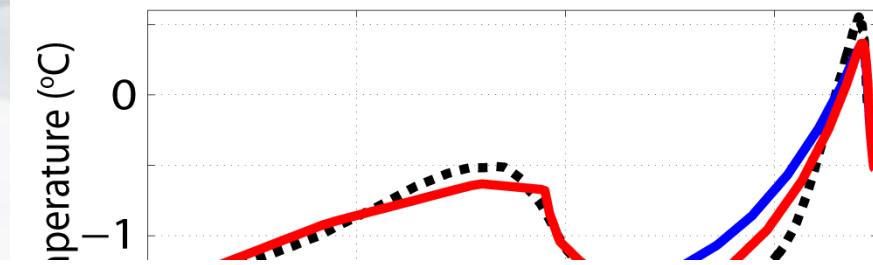
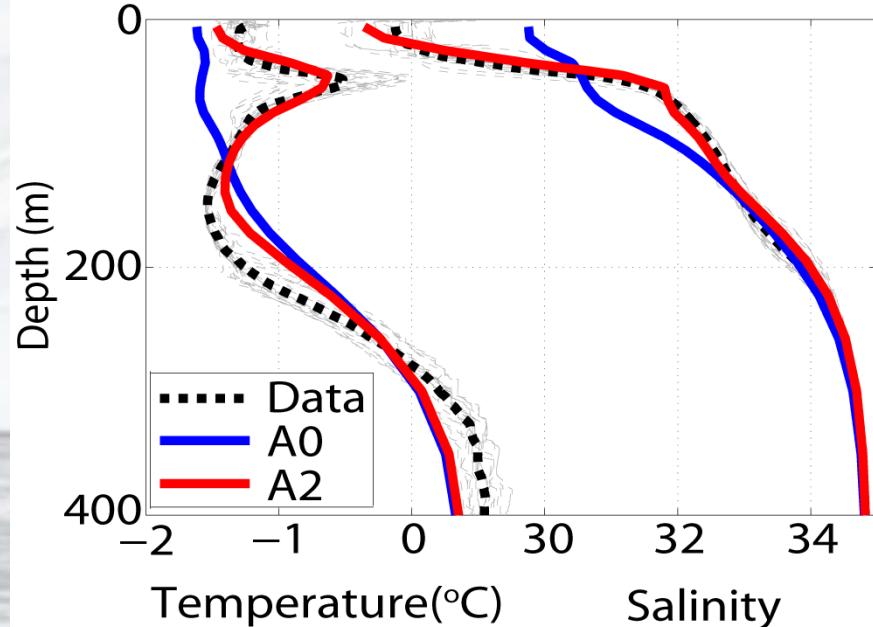
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Motivation



[Nguyen et al., 2009]



Questions:

- 1) Source of Upper Halocline Water?
- 2) Volume budget of source water?

Arctic Regional Configuration

Integration Period: 1992-2005

Ocean model:

- 9-km horizontal
- Surface BC's: JRA25
- Initial conditions: WOA05
- BC's: global solution

Sea ice model:

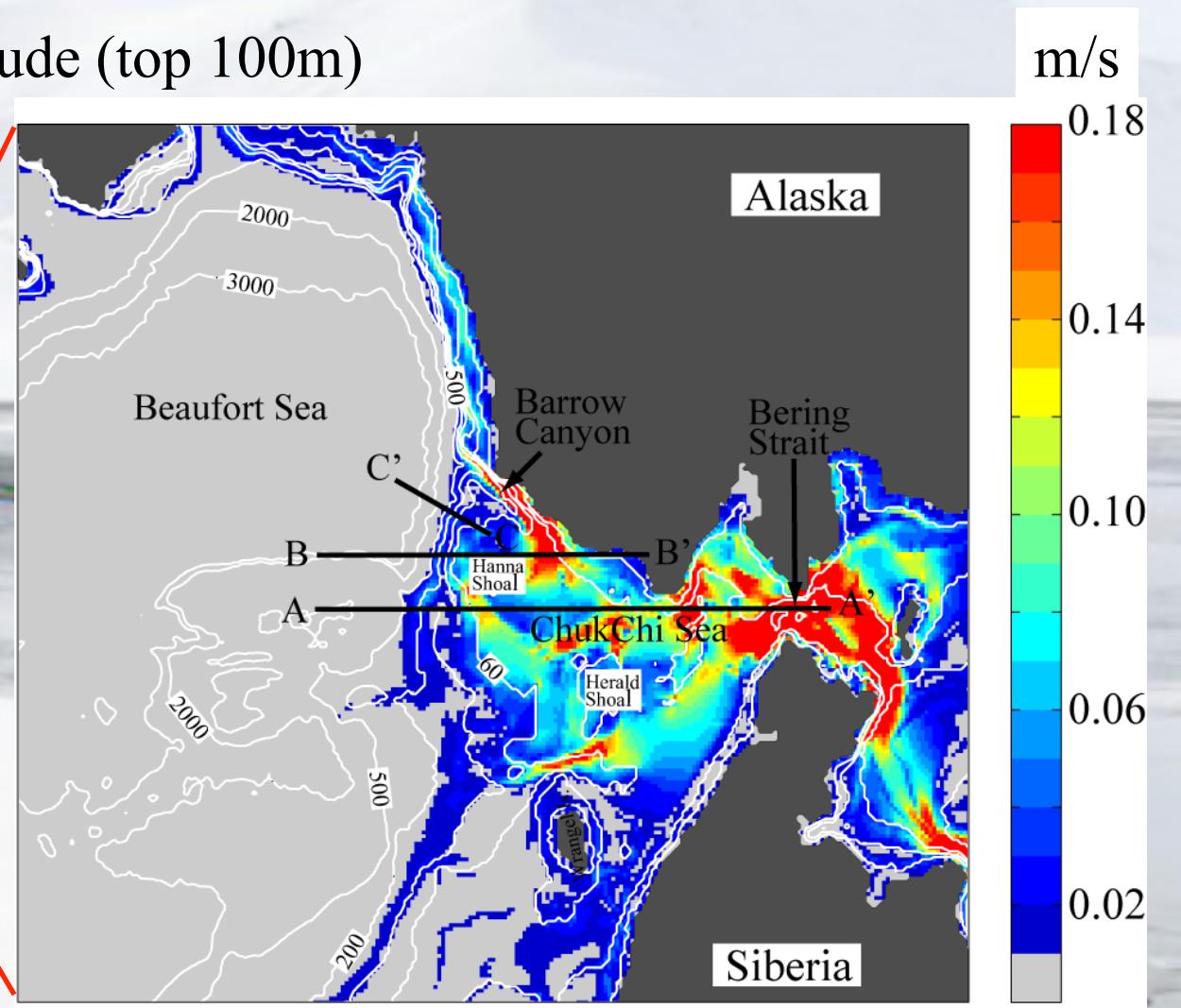
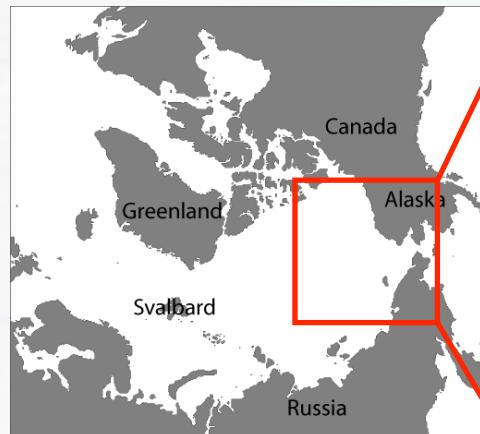
- Initial conditions: Polar Science Center



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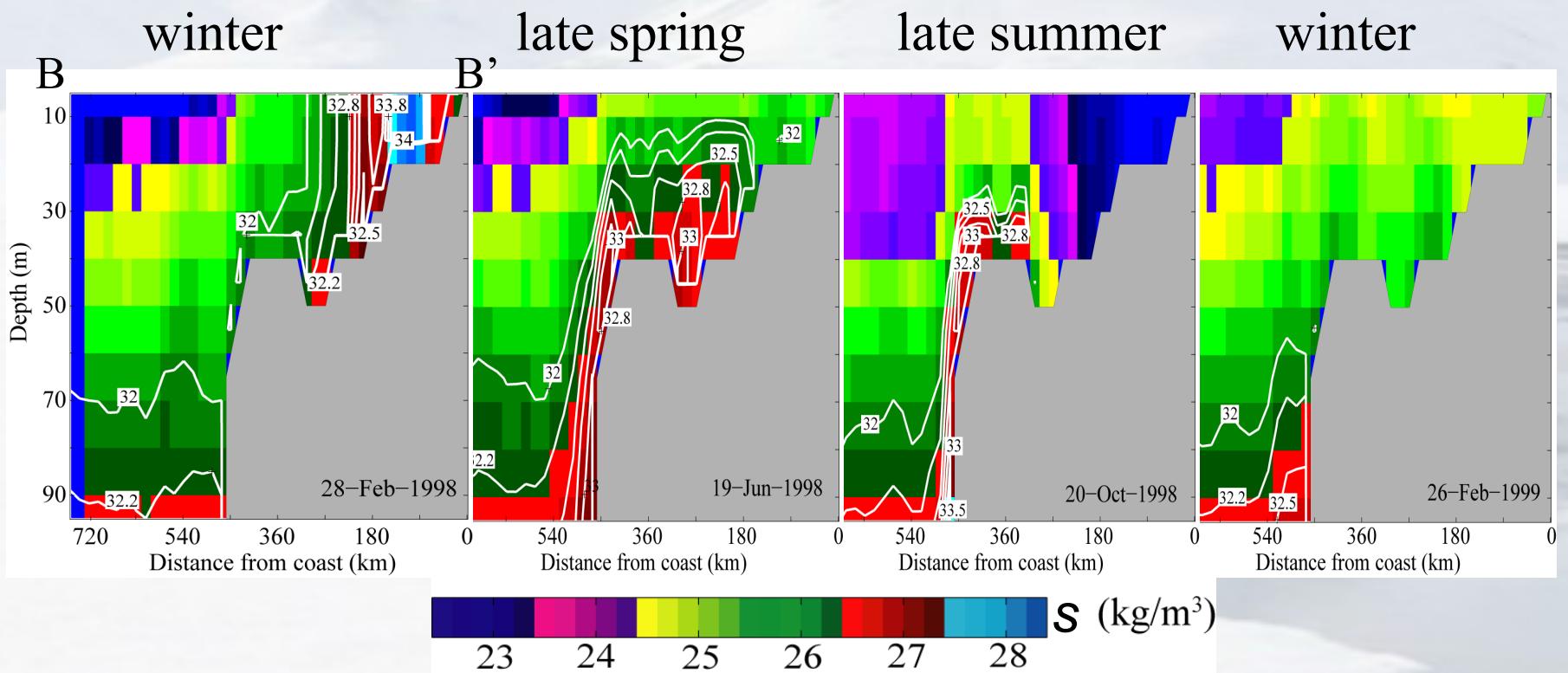
1992-2005 Mean

August velocity magnitude (top 100m)



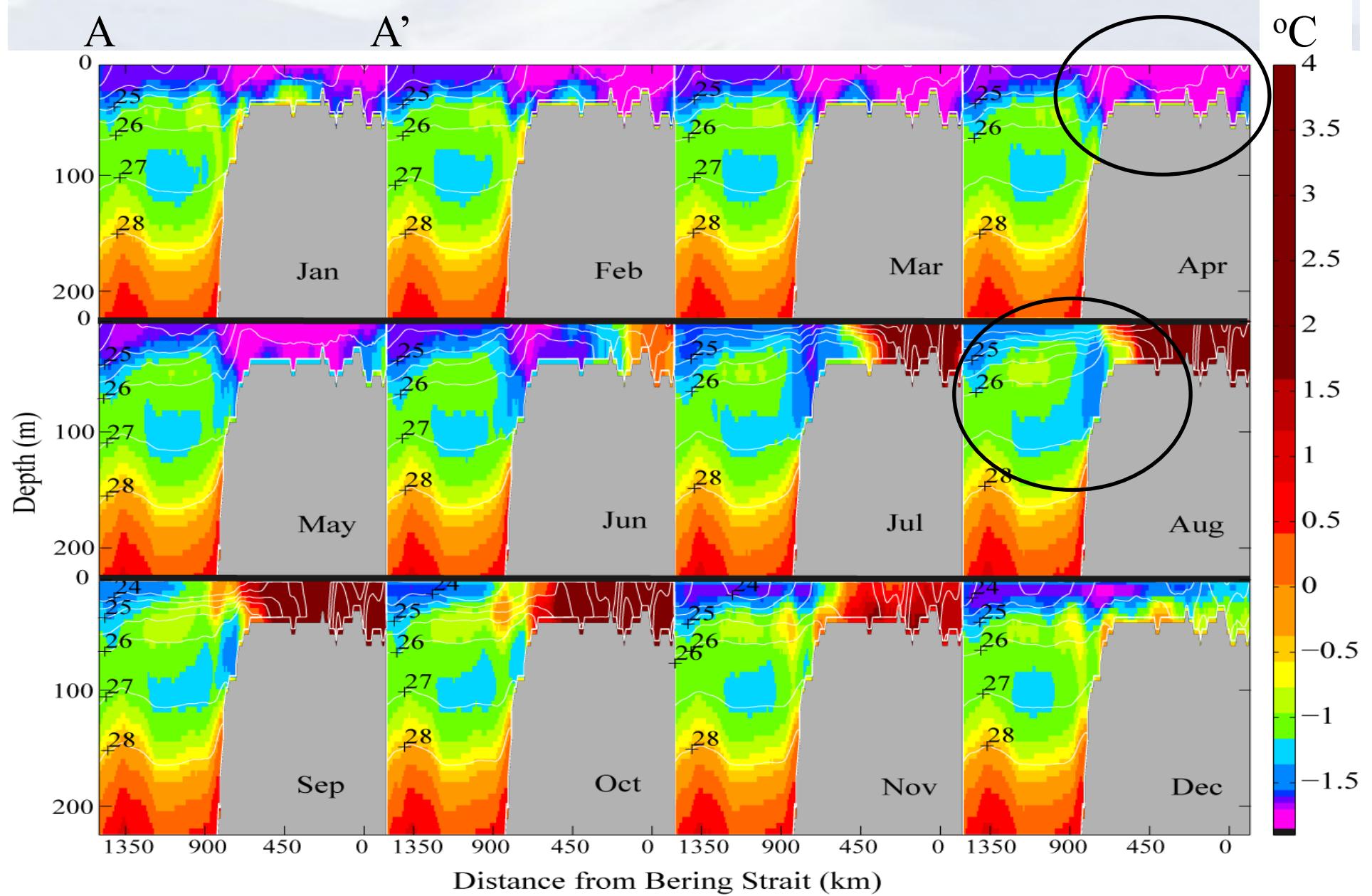
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Snap shots



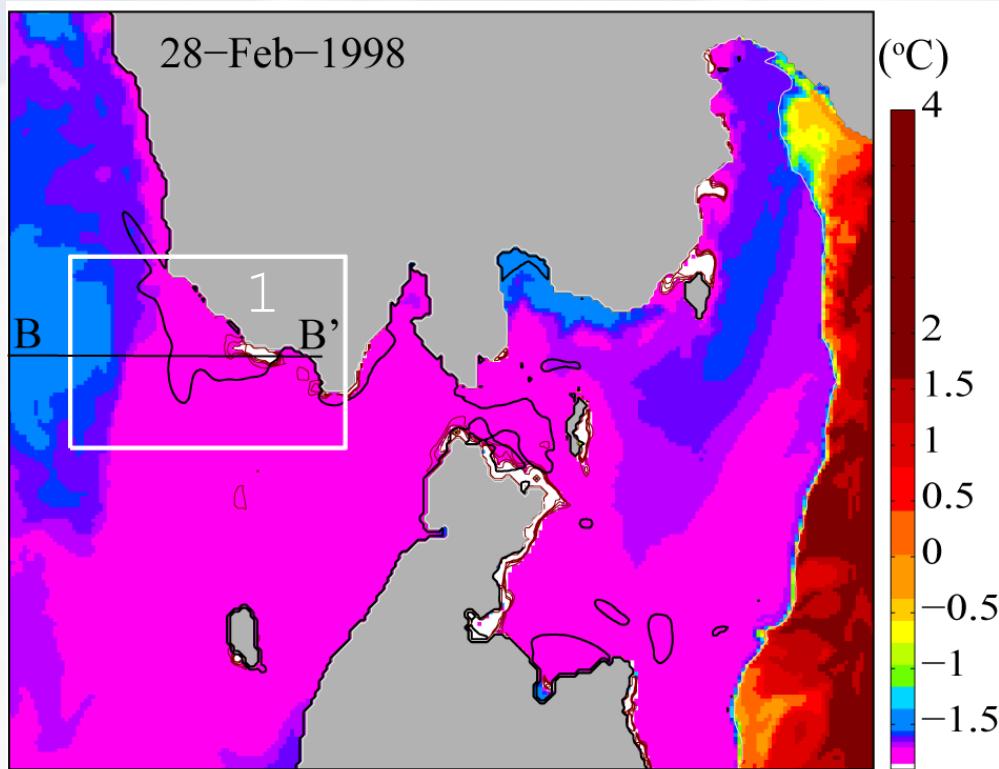
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1992-2005 Mean Temperature

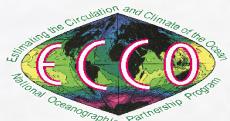


Densewater formation on shelves

Surface T / S

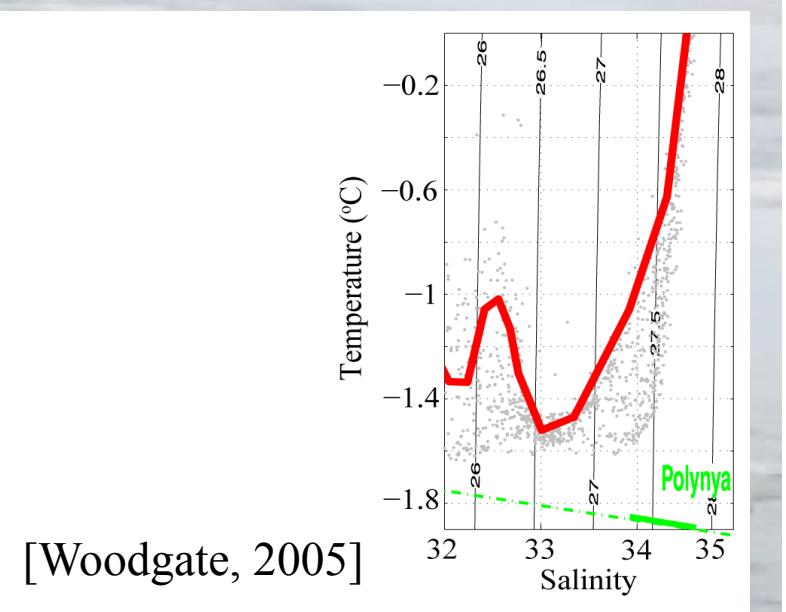
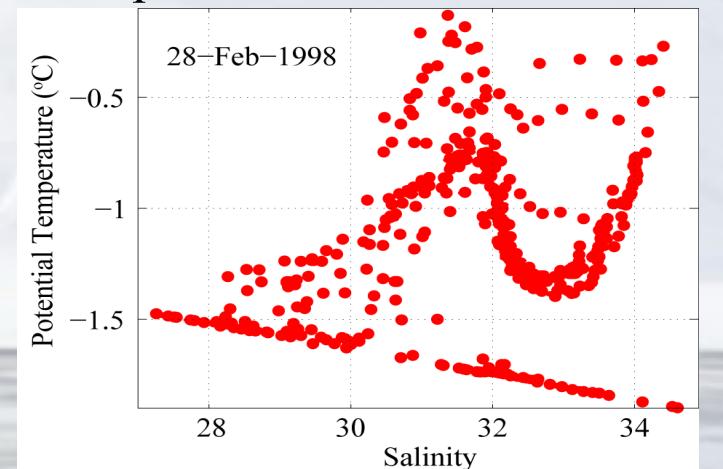


contours: $S > 33.25$, Sea-ice area = 95%

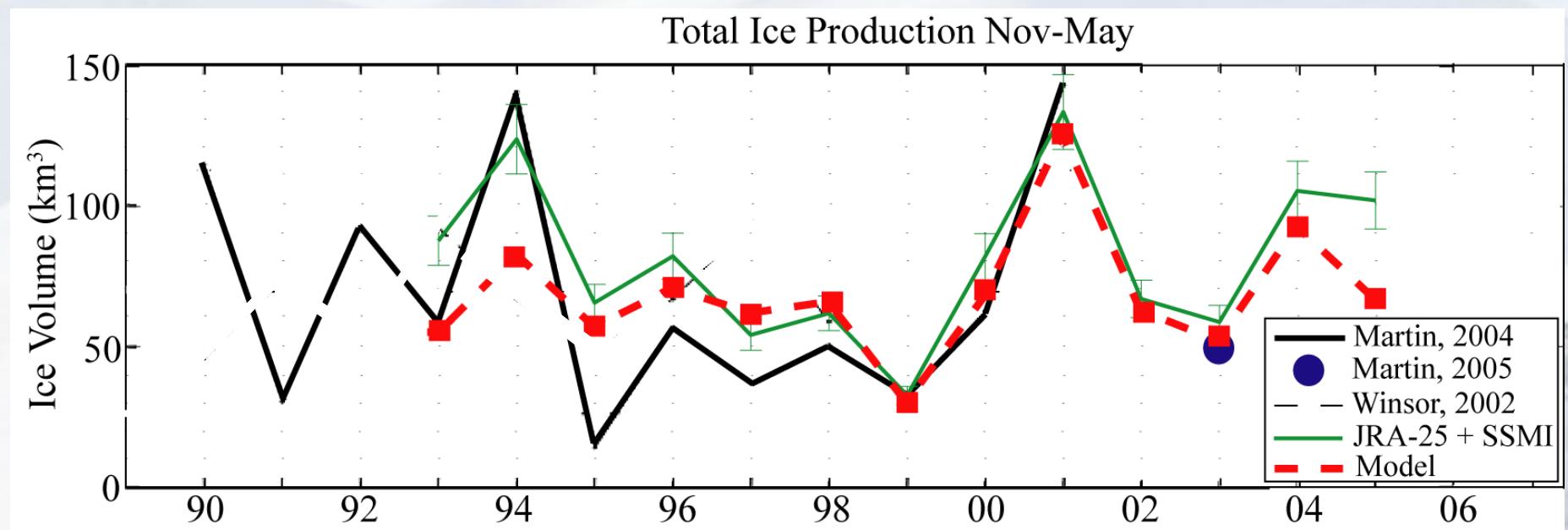


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BB' profile



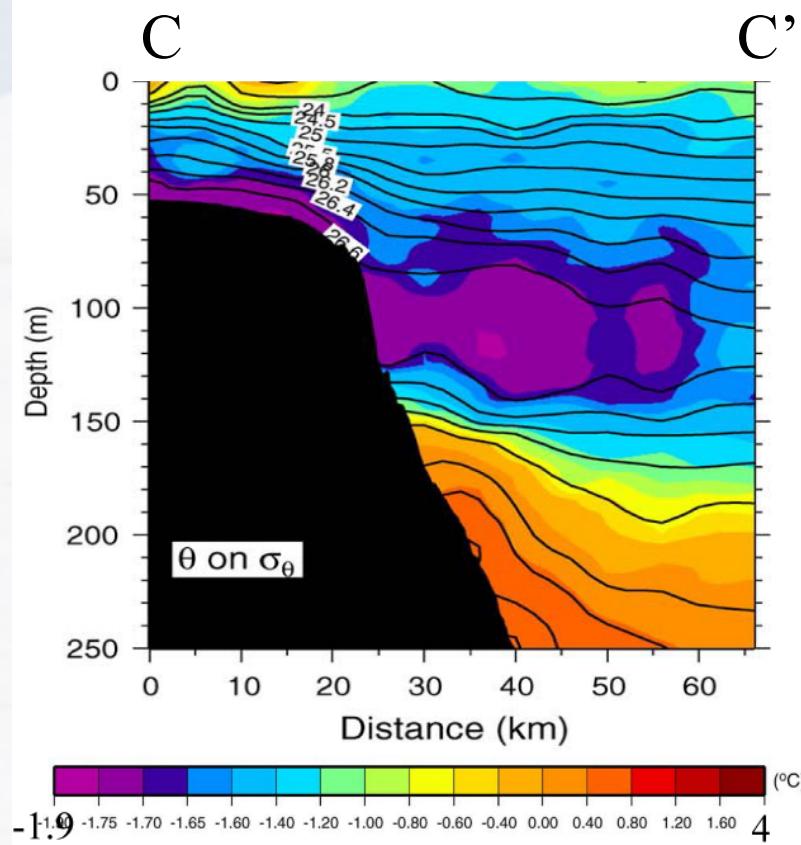
Ice productions in Region 1



Source	Temporal coverage	Ice production (km³)	Comment
[Winsor, 2002]	1978-1998	61 ± 15	Numerical model
[Martin, 2004]	1990-2001	65 ± 41	SSM/I
[Martin, 2005]	2003	42.7	AMSR
This study	1992-2005	68 ± 22	Numerical model

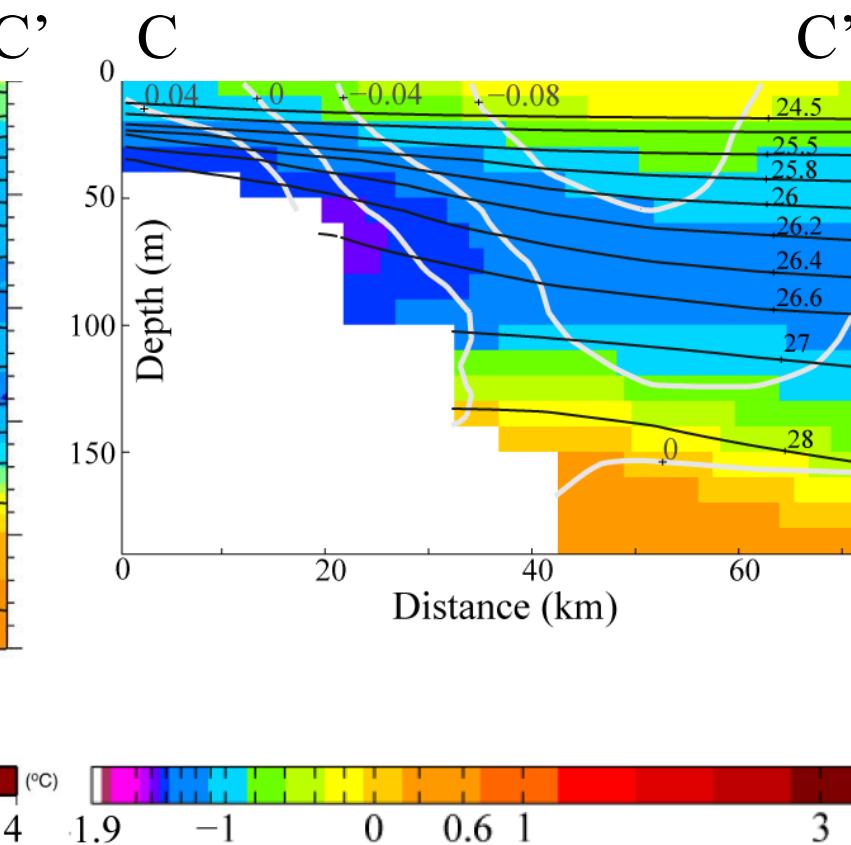
Densewater transport from shelves into Arctic interior

Observations



Summer 2002 [Pickart, 2005]

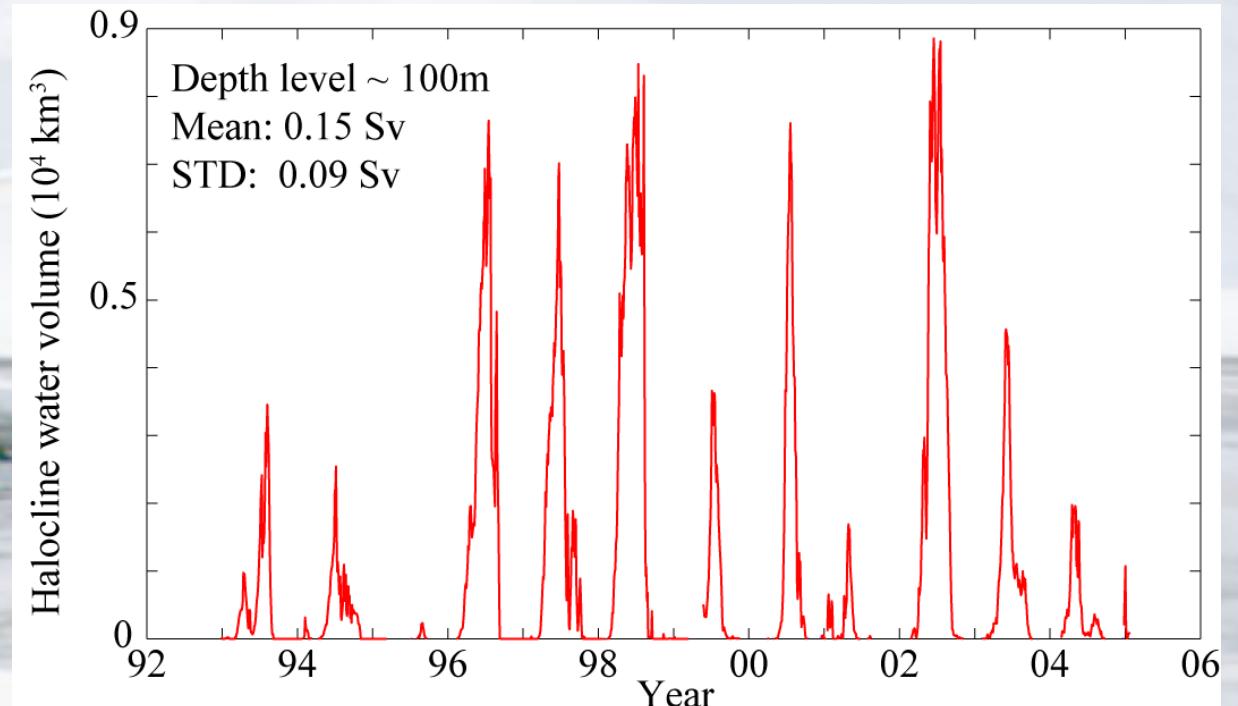
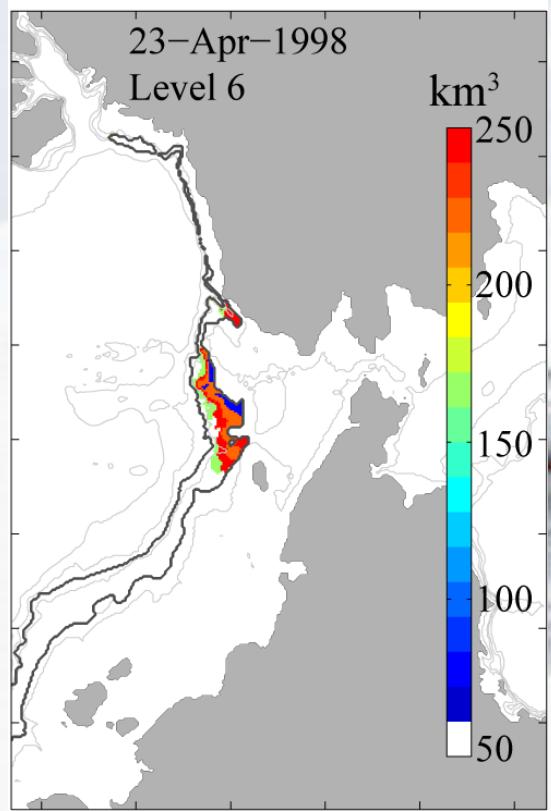
Model



August 1992-2005

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Numerical Calculation



Source	Period	Dense Water	Halocline Water
Cavalieri, [1994]	1978-1987	$0.24 \pm 0.04 \text{ Sv}$	---
This study	1992-2005	$0.12 \pm 0.03 \text{ Sv}$	$0.09 \pm 0.03 \text{ Sv}$
	1993-2005	$0.19 \pm 0.05 \text{ Sv}$	$0.18 \pm 0.09 \text{ Sv}$
	1993-2005		$0.15 \pm 0.09 \text{ Sv}$

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Summary

- Model: realistic polynyas and ice productions compared to observations
- Seasonal cycle of dense water in the Chukchi Sea
- Dense water → supplies water to the Upper Halocline
 - need to compare with observations
- Halocline → important water mass in Arctic Ocean
 - influences sea-ice



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Extra (1)

[Martin 2004, 2005]

[2] Martin *et al.* [2004] show that the thickness of thin ice can be derived from an algorithm based on the ratio of the Special Sensor Microwave/Imager (SSM/I) 37-GHz 25-km resolution vertical and horizontal brightness temperatures. For thicknesses less than 10 cm, the algorithm results compare well with thicknesses derived from clear-sky advanced very high resolution radiometer (AVHRR) data. For winter 2000 and the large coastal polynya that occurs along the Alaskan Chukchi coast between Cape Lisburne and Point Barrow, called here the Chukchi polynya, they further show that the thicknesses produced with this method can be combined with meteorological data and a heat flux model to provide daily and cumulative polynya heat losses.

2. Adaptation of the SSM/I Ice Thickness Algorithm to AMSR

[6] As Martin *et al.* [2004] show, the thin ice thickness is a function of the brightness temperature ratio,

$$R_{37} = \frac{T_{B37V}}{T_{B37H}} \quad (1)$$

where the T_B are the SSM/I brightness temperatures, and the subscripts V and H refer to the vertical and horizontal brightnesses. If h_i is the ice thickness, this function has the following form:

$$h_i = \exp[1/(\alpha R_{37} + \beta)] - \gamma \quad (2)$$

where comparison with AVHRR yields that $\alpha = 230.5$, $\beta = -243.6$ and $\gamma = 1.008$. This curve is valid for $R_{37} < 1.4$, or for minimum thicknesses of about 5 mm, and works best for thicknesses in the range 0.5 to 10 cm. Between 0.5 and 5 cm, the thicknesses have a standard deviation of about 1 cm, for thicknesses as large as 12 cm, the standard deviation is about 2 cm. In the following, we assume that the same algorithm can be used with the AMSR R_{36} ratio, where R_{36} is defined in an identical way to equation (1).

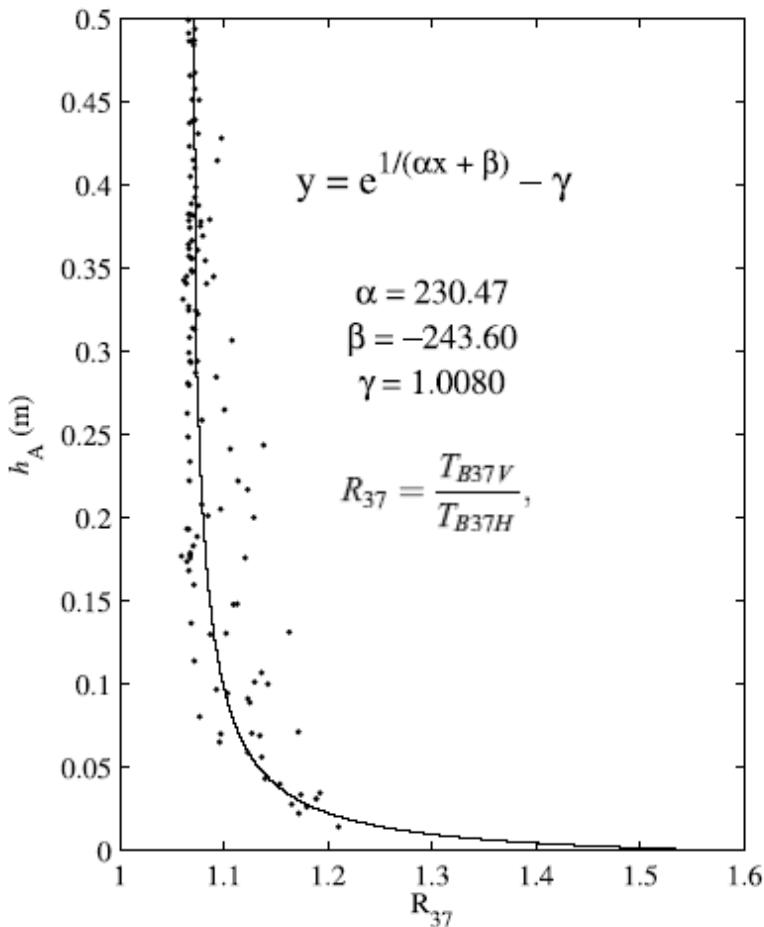


Figure 3. Scatterplot of the AVHRR-derived ice thickness on the vertical axis and the SSM/I 37 GHz V/H ratio on the horizontal axis from day 72, 2000, which was the clearest day in our record. The solid curve shows an exponential fit to the data. See text for further description.

easily calculated. For a thickness of 5 cm, the random error is ± 0.3 cm; for a thickness of 10 cm, ± 1 cm; for 15 cm, ± 2 cm; and for 20 cm, ± 3 cm, so that the random error increases rapidly with thickness. This demonstrates that the

Heat Loss, Ice and Dense-water and Halocline water productions

[Cavalieri 1994]

Heat Loss:

$$H_L = (8.64 \times 10^4) \cdot A \cdot F_{\text{net}}$$

Ice Production:

$$V_i = (8.64 \times 10^4) \cdot H_L / (\rho_i \cdot L)$$

Salt Production:

$$S_F = \rho_i \cdot V_i \cdot 0.69 \cdot s_w$$

Dense Water:

$$V_D = S_F / [\rho_e s_e - \rho_w s_w]$$

Halocline Water**:

$$V_H = V_D (s_e - 32) / (32.85 - 32), s_e > 32.85$$

$$= S_F / [\rho_h s_h - \rho_w s_w], s_e < 32.85$$

** Assumptions:

- sea-ice production yields enriched water with salinity increases 1.5-2 psu
- enriched water mixes with mixed-layer water to produce halocline water
- cold halocline water has an average salinity $s_h = 32.85$ psu
- enriched water has salinity $s_e > s_h$

Variables:

F_{net} : total ocean-to-atmosphere heat flux

A : open-water area

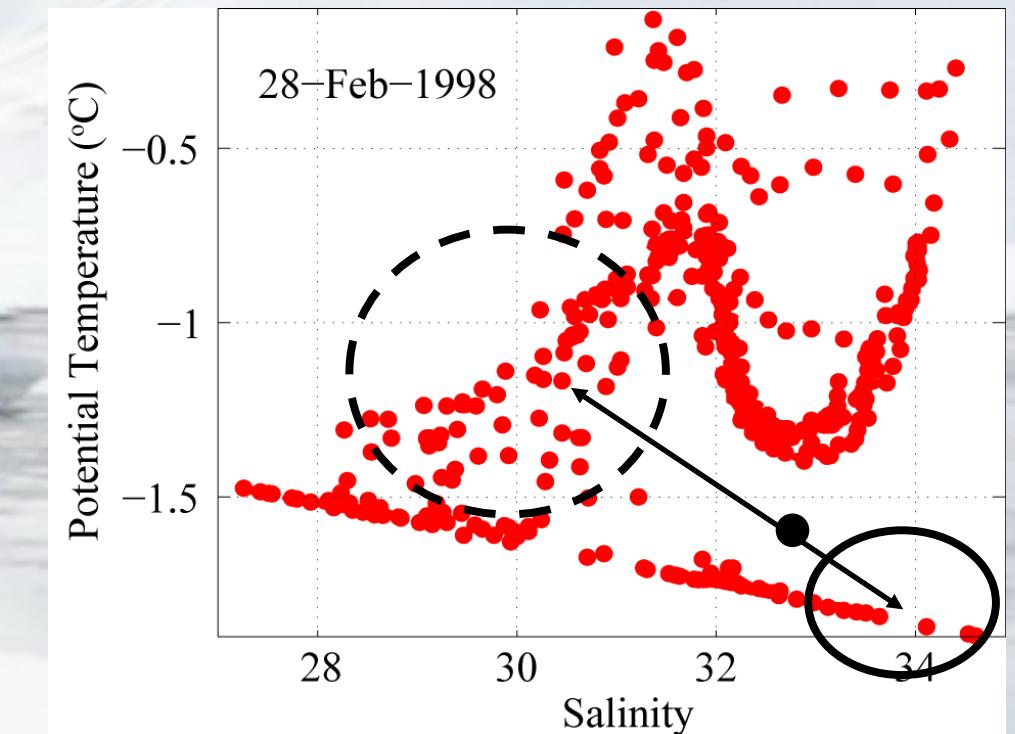
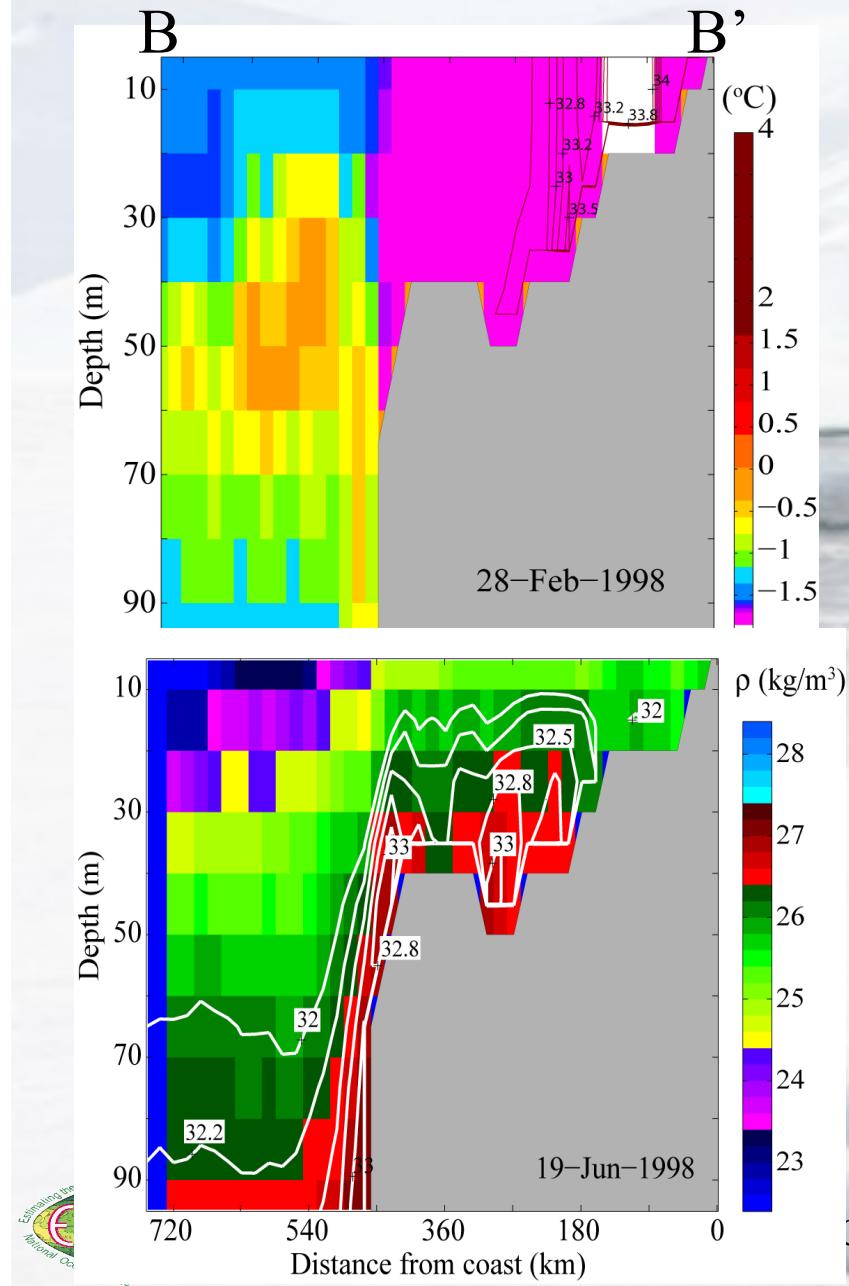
L : latent heat of fusion

ρ_i, V_i : sea-ice density and volume

ρ_e, s_e : enriched water density and salinity

ρ_w, s_w : background water density and salinity

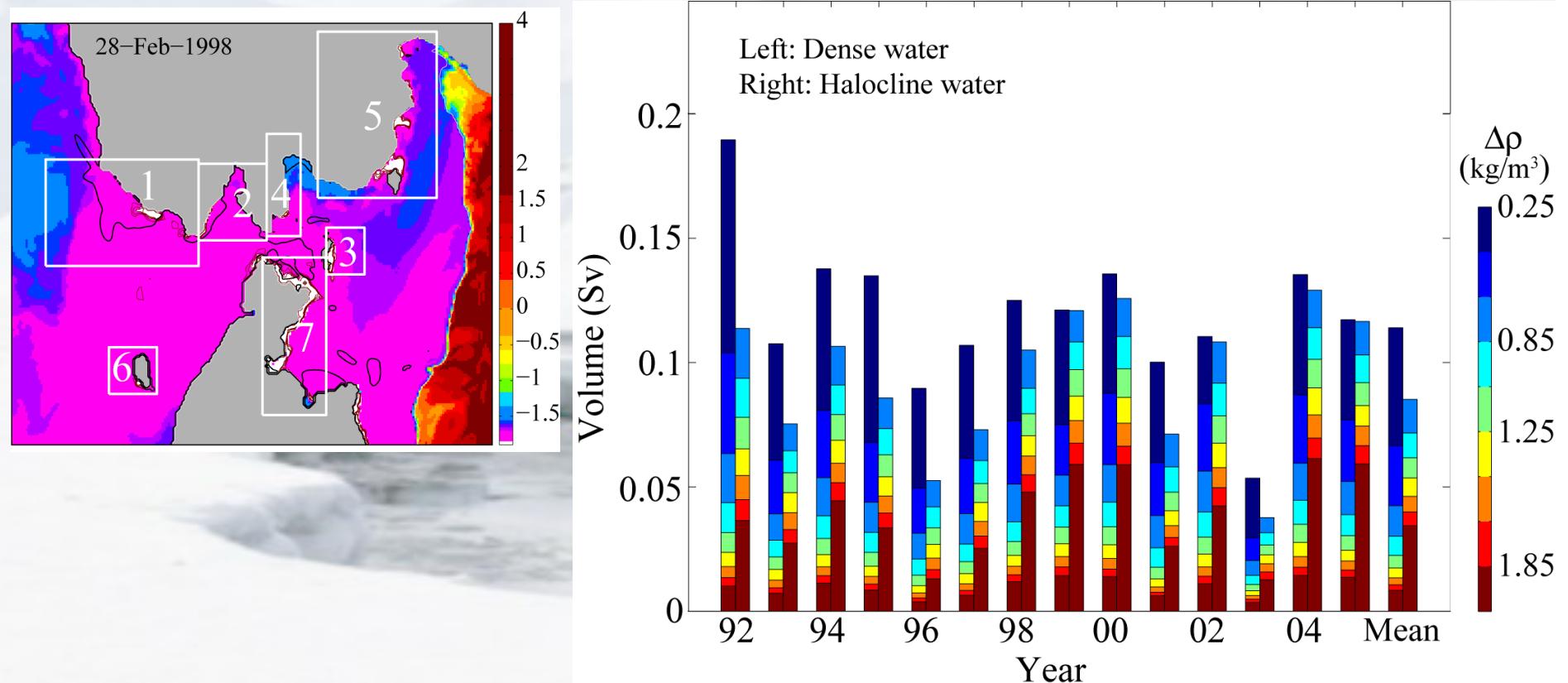
Dense water and Halocline water calculations:



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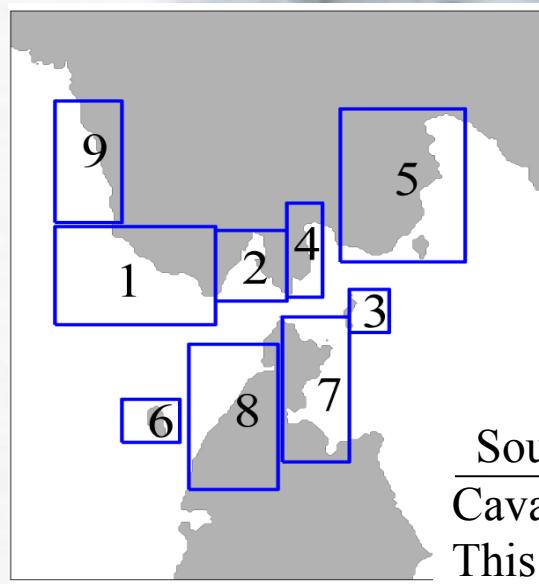
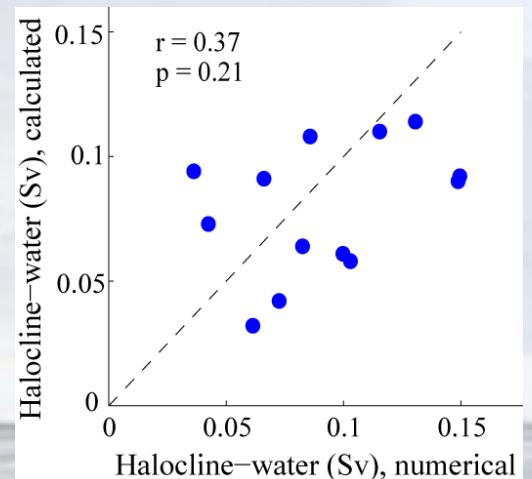
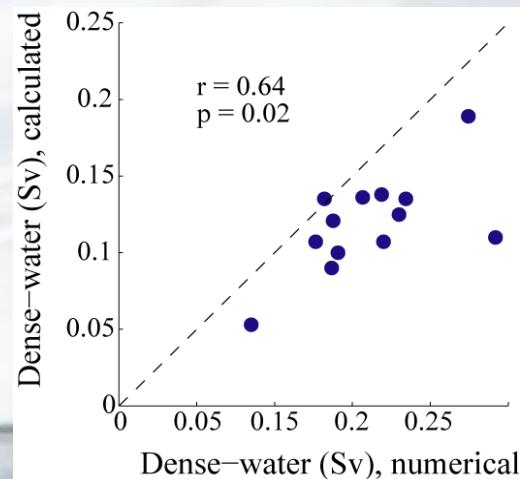
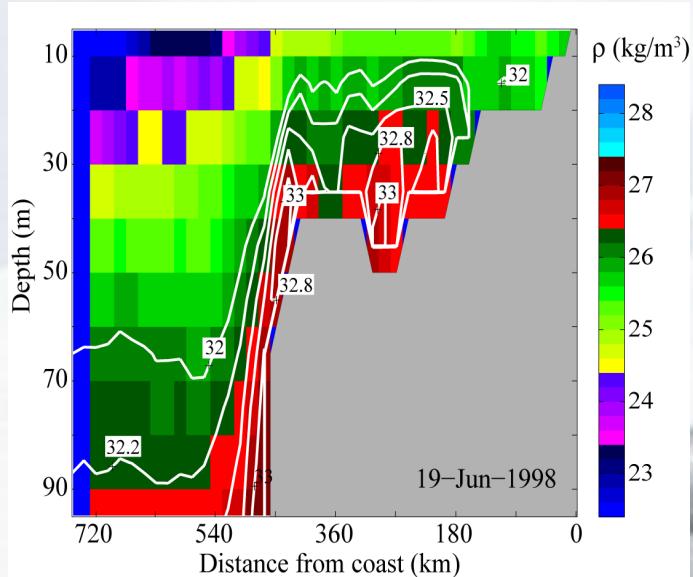
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Net Halocline Water Production



Source	Period	Dense Water	Halocline Water
Cavalieri, [1994]	1978-1987	$0.24 \pm 0.04 \text{ Sv}$	---
This study	1992-2005	$0.12 \pm 0.03 \text{ Sv}$	$0.09 \pm 0.03 \text{ Sv}$

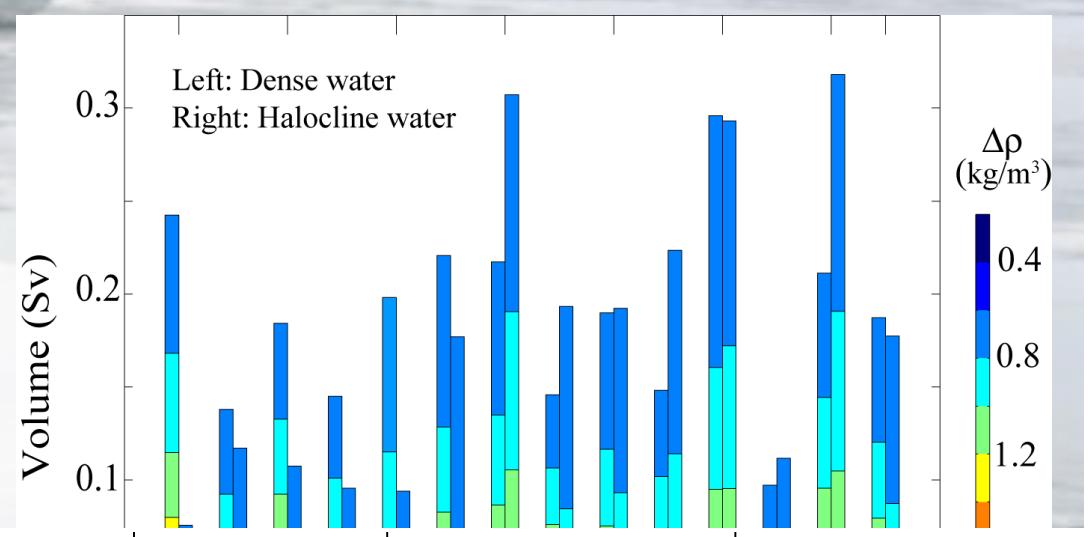
Numerical Calculation (1)



Source

Cavalieri, [1994]

This study



Period	Dense Water	Halocline Water
1978-1987	0.24 ± 0.04 Sv	---
1992-2005	0.12 ± 0.03 Sv	0.09 ± 0.03 Sv
1993-2005	0.19 ± 0.05 Sv	0.18 ± 0.09 Sv